# PARTNERSHIPS IMPLEMENTING ENGINEERING EDUCATION: GRADES 4-6

An Interactive Qualifying Project Report

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by


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# Abstract

An engineering curriculum was developed for the Worcester Public Schools (WPS) grades four through six by the Partnerships Implementing Engineering Education project team. Existing lessons from previous project groups along with newly created lessons make up the 87 finalized lessons. These were produced to meet the WPS benchmarks and evaluated by observing the implementation of them in classrooms. Hard copies of the lessons in uniformly formatted binders and supply bins consisting of supplemental materials were presented to the participating schools.

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# 1. Executive Summary

Worcester Polytechnic Institute (WPI) undergraduate students completing their Interactive Qualifying Project assisted the Partnerships Implementing Engineering Education (PIEE) project for grades four through six. This was a collaborative effort between Worcester Public Schools (WPS) and WPI, sponsored by the National Science Foundation (NSF), to raise awareness of engineering in the WPS curriculum. The engineering lessons created were based on Massachusetts Department of Education Curriculum Frameworks and WPS benchmarks. Binders containing all lessons and engineering bins for supplemental materials were produced and provided to Elm Park Community and Midland Street Elementary Schools.

To better understand the objective of the project three areas of engineering education were researched. The topics include national versus international engineering education, engineering education for grades K-12 , and minorities and women in the profession of engineering. It was found that U.S. students are falling behind their international peers in science, technology, engineering, and mathematics (STEM) studies. To compensate for this finding, the U.S. has begun to organize resources for elementary and secondary educators. More focus has been placed on minorities and women in order to diversify the engineering community. The stereotype that only white males become engineers is being broken by implementing engineering with younger students of both genders and many ethnic backgrounds in the U.S.

The goal of this project was to create a sustainable engineering curriculum capable of implementing the basic fundamentals of engineering in grades four through six. To accomplish this task, a set of uniformly formatted binders (one binder per grade) with all lesson plans and supplementary materials had to be created. Both Midland Street School and Elm Park Community School should receive a copy of the binders and engineering bins. These engineering bins were to include all of the materials necessary to carry out each lesson in the developed curriculum. Lessons needed to be flexible so that they could be easily altered to parallel with the changes that will occur with the evolution of the field of technology and engineering.

The methodology of reaching the goals of the PIEE project, grades four through six, consisted of the completing the main deliverable, the lesson plans, necessary to make the program a success. To produce these lessons, each of the four members of the team was partitioned by the grade level they would be focusing on. Much of the work for each grade level was similar in some manners and each team member followed the same basic guidelines. The process of producing these lessons consisted of four phases: organizing existing materials, modifying/improving the curriculum, formatting, and finalizing the final products.

It was found that interactions with both teachers and students had a profound effect on the production of both lessons and supplemental materials. The students provided insights into how well the material was being understood and subsequent changes that needed to be made. The teachers provided helpful feedback through written comments, reactions, and conversations that allowed for modifications to be made to the lesson plans, which made them more efficient and straightforward when used in the classroom.

The PIEE, grades 4-6 project had multiple successes and faced some challenges. The project successfully created a curriculum with engineering concepts, in a neat and organized manner. It was verified that the lessons within the curriculum could be used by teachers without an engineering background. Student's enthusiasms implementing the engineering design process increased. Educators gained a better understanding of the difference between engineers and scientists. Large engineering bins full of the materials needed to complete the activities in the lessons have been created. However, a difficulty of the project was communicating ideas and concepts with the teachers and increasing their comfort level with teaching engineering.

At the conclusion of this project recommendations were formed to assist future implementation of engineering curriculums in public schools. Most of these included providing information to the administrative staff on how to sustain the integrity of the project. It was also recommended that materials be provided to teachers that allow them to stay current with the dynamic field of engineering and maintain students' enthusiasm in engineering education.

# 2. Introduction and Problem Statement

The National Science Foundation has provided the Worcester Public School System and WPI with a grant to develop the Partnerships Implementing Engineering Education (PIEE) project. This project has been created to develop a K-6 curriculum that incorporates the engineering concepts that the State of Massachusetts has developed into their frameworks for education in the elementary level. WPI graduate students have taken the role as Fellows in this partnership with both the students and faculty of the Worcester Public Schools. These fellows organized the structure of the entire project and act as leaders for the undergraduate Interactive

Qualifying Project (IQP) students who are working to finalize and complete all the deliverables in its 3rd and final year.

To successfully complete the project for grades 4-6, sufficient information and documentation must be provided to all Worcester Public Schools for teachers and students on how to use and implement engineering concepts not only for this year, but for years to follow. This criterion posed the problem of creating and formatting lesson plans and supplementary materials which needed to meet each and every Worcester Public School Engineering benchmarks for grades 4-6. These lesson plans had to be easily adaptable by the teachers and students of the Worcester Public Schools and incorporate a modification process due to the dynamic nature of the field of technology and engineering. The curriculum had to include a means of evaluation in order to test the effectiveness of the lessons as future generations used the lessons to teach engineering concepts. In all, the PIEE project was established to develop the means to implement dynamic engineering concepts into the Worcester Public Schools curriculum.

# 3. Literature Review

Technology and engineering are an integral part of today's society. Everything from the buildings worked in to the modes of transportation used, were designed and created using engineering techniques and the latest technological advances. Standing as one of the leading countries of the world, the United States has recognized the importance of technology and engineering. Over the past half-century, the U.S. has rapidly strived to transform the nation into a technological based society. During this time, the U.S. has been working to increase the attention citizens give to the importance of engineering. Most recently, the United States has begun to fall short of other countries in engineering education. To solve this dilemma, the U.S. has been building better support to educate younger generations and expose them to the variety of careers engineering and technology offer. In the past engineering has been considered an occupation for males only, so the push for minorities and women to enter the engineering field has boomed. The U.S. is on a mission to amalgamate their engineering community with all races and genders in order to create a variety of professionals in the field. A more diverse group of engineers provides more ideas which leads to more innovative products.

## 3.1 National vs. International Engineering Education

The consistently increasing world of technology over the last half-century in addition to the job market's subsequent demand for a highly educated, skilled technical workforce has created a high demand for engineering knowledge and education. Quality of life is growing ever more dependent on engineering. Engineers are immersed in everything from basic social/consumer needs to life saving infrastructure, medicine, and technological improvement. The skills necessary to continue improving and advancing technology and engineering need to be developed by those interested in entering the field because the U.S. expects to maintain a constructive future as a world leader. However, due to a lack of engineering awareness, American students are falling behind international peers.

Nationally the average on mathematical scores has improved, but science performance has not. The National Assessment of Educational Progress (NAEP) reports student achievement in science and mathematics using four categories: "Below Basic," "Basic," "Proficient," and "Advanced." The word, "proficient" describes a solid academic performance for each grade assessed. In the 1996-2000 NAEP*,* the percentage of U.S. students in grades 4, 8, and 12 that performed at or above the "Proficient" achievement level in mathematics and science was less than one-third [1, p. 9]. Also, according to the 1996-2000 NAEP more than one-third of U.S. students don't have a basic level of understanding in these subjects [2, Ch 1, p. 51]. Even though U.S. students have been showing improvement in both math and science in recent years, they remain less educated than students in other developed countries [2, Ch 1, p. 51]. There needs to be drastic changes made to the nation's science and engineering education in order to produce an engineering workforce that is well prepared in science and mathematics which would secure America's competitive edge [3, p. 6].

In a study that compared international and national education, the U.S. lagged far behind in both elementary and secondary math and science education. National and international figures were compared for both the Trends in International Math and Science Study (TIMSS) assessment tests and the Program for International Student Assessment (PISA) tests. The TIMSS assessment tests measured the recollection of curriculum-based knowledge and skills. This study compared fourth and eighth graders between 1995 and 2003, in both developing and developed nations which agreed to participate. The American student's average for this study was above that of the participating international average [2, Ch 1, p. 21-22]. However, comparatively, the

PISA tests measure the application of mathematical and scientific concepts and skills. This study's scores were composed of the 30 Organization for Economic Co-operation and Development countries and showed a lower average for American 15-year olds compared to the international average [2, Ch 1, p. 23]. These assessments showed that the United States student populace, although adequate in memorizing and regurgitating knowledge, lacks the essential skills to apply this knowledge. The relation and use of scientific and mathematical knowledge is directly linked to engineering.

After secondary school, the number of U.S. students that try to obtain science and engineering degrees is far less than that in the international scene. Specifically, 6% of U.S. undergraduates study engineering, where in most of Europe that number stands at 12% and in China 40% [4, Ch. 1, p. 8]. Why is it that American students lack the initiative to become engineers? A factor that contributes to this problem is that out of the enormous number of students coming out of elementary and secondary school only a small amount are taught basic engineering skills and develop an interest in this area of study. This is due to the lack of awareness for engineering by elementary and secondary school teachers and a weak implementation of engineering topics in the mathematics and scientific curriculum [4, Ch. 3, p. 26-27].

Most other nations have a national education system that can institute changes in the curriculum more immediate than this country's K–12 system, which is operated by nearly 16,000 independent school boards [5, p. 6]. To address this dilemma and the rising problem of inadequate engineering education, organizations like the National Science Foundation have created programs like the PIEE project. This program aims to play a role in rising general awareness of what engineering is and its importance and to improve how it is being incorporated at the elementary level. This is a start to increasing America's competitive edge in the world market and economy. Human capital is one of America's strongest assets and the efficient use and transformation of this into a strong engineering community is one of the nation's greatest priorities [4, Ch. 1, p. 7-8].

To help raise engineering awareness and provide elementary students with curricula that will improve the development of problem solving skills in both math and science, WPI has been funded by the NSF to implement an experimental solution. This solution hinges on one main issue, which is to provide the elementary schools with engineering information and materials that will effectively work in conjunction with the existing science curriculum.

## 3.2 Engineering Education K-12

Technology and engineering have become essential elements of today's world, especially in America. Many citizens rely on a multitude of the conveniences current technology offers us. In order to maintain a constant improvement in U.S. technology and engineering, the country must continue to have students going to school to become engineers. Each year however, students' interest in science, technology, engineering, and mathematics (STEM) in elementary and high school education has decreased. For example in 2005, *The State of State Math Standards* gave the national average grade in mathematics a D, with only three states in the entire US receiving an A, one of which was MA. Also "the latest ASEE survey indicates that out of the 5,936 students who graduated with bachelor's degrees in engineering technology during the 2002–2003 academic years, only 11.7% were women" [6]. As a direct result, multiple organizations have attempted to grab the future generation's attention by developing more appealing lectures and lessons on engineering concepts. This has been done for the most part through the collaboration of partnerships and fellowships with institutions or companies and nearby public schools, similar to the PIEE project.

> "Several individuals commented at the summit that the current K-12 system does not provide a sufficiently rigorous education to large numbers of students, particularly in the inner-city schools, to allow them to enter and succeed in an engineering program. As a community, engineering educators are working to assist the K-12 community to understand the engineering profession and how engineering activities can invigorate the teaching of mathematics and science in the K-12 classrooms. Many programs are actively engaging K-12 districts and faculty across the country…" [7]

There are multiple online resources becoming available for educators and students in grades K-12 to expand their engineering curriculum. There are many K-12 outreach programs for engineering education sponsored by over 150 universities, colleges, corporations and foundations in the United States today according to the ASEE database [6]. These programs offer a variety of different opportunities for students and educators to attend. Not only are these programs aimed to increase engineering enrollment they are simultaneously working to diversify engineering, educate the future generations, and teach instructors how to apply engineering concepts to the general science and math subject matter. The benefits of these goals are stressed in the various mission statements of the different projects.

Some of the programs offer field trips for students to meet engineers and participate in activities related to engineering concepts. This allows students to meet people practicing the profession and aspire to also become a respected engineer. Through the various presentations engineers give to the students at such gatherings, the students not only learn about different types of engineering and the problems each solve, they also learn the importance of holding integrity in a profession such as engineering. The speakers present their accomplishments and then note that all of their success is attributed to the time, dedication, and perseverance they put into their work to make it as accurate as possible. They also share how engineering work allows individuals to utilize their flair for creativity, which can be enjoyable in many cases. Presenting engineering as a job that requires hard work that you may reap self satisfaction from will help increase interest in young students.

There are lessons posted on some websites that teachers can access and download easily. The site that provides this curriculum online, http://www.teachengineering.com/search.php, is funded by the National Science Foundation, US Department of Education, and the National Science Digital Library, and is very similar to the database the PIEE 4-6 project will be providing to teachers via the web by the PIEE integration team [8]. The lessons are organized by grade and subject matter, which is the goal the PIEE integration team has of organizing the curriculum the PIEE project has developed. The site also includes a section where educators can post lesson extensions, problems incurred while implementing the lesson, and any lessons they have developed on their own that pertain to engineering. The site also emphasizes the importance of creating engineering lessons that fulfill the requirements of math and science state frameworks. The engineering design process requires outside research and understanding of basic math and science concepts, which is how the math and science that needs to be covered in class can be.

The assortment of goals each program has is what makes this effort to raise awareness so profound. Jeffers provides a brief synopsis on over 50 of the different programs being offered in his article [9]. Each program has the same overall objective of communicating engineering to younger students, but executes it in different ways such as the two described above. In the newsletter that ASEE sends out monthly there is a multitude of information about all of the various seminars available for anyone to sign up for that focus on engineering education in grades K-12. The newsletter also provides the latest statistics on STEM education in grades K-12 across the country, articles written by undergraduate and gradates students participating in outreach programs such as PIEE, and even feature articles on exemplary lessons executed in classrooms that have had students use the engineering design process to create truly original designs. This newsletter should be distributed or accessed by every elementary and high school teacher in America to assist the country's goal to maintain a population of technologically advanced designers.

Younger children truly have the capacity to practice the fundamentals of engineering and are impressionable enough to mold into engineers [10]. This is the main reason why it is so important to implement engineering concepts in the classrooms at a younger age. As excellent as the programs are that work with high school aged students on engineering, many of the students at this age have already formulated an opinion of whether or not they like or dislike engineering. Once a student at this age has decided they do not like expressing their creativity and math and science skills in order to solve problems, it is merely impossible to "change their mind". Presenting engineering to students in grades K-6, as PIEE is geared to do, gives more likelihood that students will be willing to give the new lessons a try and a higher percentage of students will find a way to enjoy the tasks given to them. Most students at this age have the power to explore and create, which are two necessary tools that all engineers need to use in order to achieve their goals.

As of 2004, Massachusetts was the only state that included engineering in their K-12 frameworks [9]. This is a rather shocking statistic found in recent research. The MA frameworks initiative of is commended for its efforts to help teachers implement engineering concepts. Although it is unbeknownst to the individuals working at the MA department whether or not every single teacher is actually meeting all frameworks set by the MA education department, it is assumed and expected that public educators follow the guidelines set by these frameworks in the lessons they teach. The PIEE team for grades 4-6 used the engineering frameworks set by the state to shape the lessons created and implemented in the classrooms. The goal of the lessons created was to offer active learning through hands-on activities, inquiry-based learning, supplemental materials when necessary, and teacher involvement.

Engineering education at the elementary level is in the process of being reformed for the next generation. Not only are students being pushed to understand the processes of engineering and the teamwork collaboration necessary to complete designs, the educators and community are also being targeted. Preparing the various websites that give students the initiative to learn about engineering also provides the information to the community. "These efforts and others represent real progress in changing the public understanding of engineering and should, over time, begin to enhance the recruitment of students into engineering who are knowledgeable of the field and prepared academically for its rigors"[7].

## 3.3 Minorities and Women in the Profession of Engineering

One of the many obstacles American society faces in the future of engineering is to find ways to include and welcome more minorities and women into the profession. Many minorities are hindered from the profession because they lack the education necessary to succeed in the college programs and do not have the financial capabilities to afford the higher education. Women are deterred by the overpowering population of white males, and are still influenced by the stereotypes that females are not as strong academically in the areas of science and technology that the U.S. society impresses upon young women.

American society's goal is to promote STEM in a positive manner in order to get more minorities in the workforce in these areas. To do so, the interest and awareness of necessary college preparatory work in these areas need to be provided to children in elementary education. Increasing the opportunity for minority students to receive financial aid for higher-level education to make it possible for them to reach the goal of attaining a college degree needs to be improved. Finally, stereotypes need to be rid of that are tied with careers in these fields, especially engineering. These three things would diversify the workforce of engineers significantly.

Many authors have presented their opinions on the exact reasons why the percentage of minorities in engineering is significantly lower than that of white males. "A decrease in corporate support for outreach programs during the 1990s and after 9/11; a declining economy in the early 1990s and between 2000 and 2004; and an overall lag in minority academic performance at the K-12 level are factors educators have cited as hurting minority participation" [11]. In addition to these factors, there are also reasons why minorities have low representations in college or any type of further education after high school in general. The stereotypical minority family in the major cities of America is of low-income. Most minorities are raised in homes that do not discuss the opportunity of attending college or pursuing any career that would require spending money before they begin working. Multiple minority families are unaware of the opportunity that lies in attending school after receiving a high school diploma. Many parents think it is more important and realistic for their children to being working full time as soon as they receive a high school diploma, or even before.

Reasons why minorities do not attend colleges and schools that provide technical or engineering degrees are related more to the environment that the typical minority family resides in. In America, the majority of minorities reside in urban settings, and attend public schools. It has been proven in case studies that these students' performance does not match the national average of students in America. In order to pursue a career in technology or engineering, one must have a strong academic background in both math and science through elementary and high school education. The performance gap between minorities and whites is even significant within the urban settings. "White students in mathematics out performed African Americans and Hispanics in mathematics in 2000 by 24-41 scale score points. Less than one half of one percent of underrepresented students score at the advanced level of proficiency in mathematics on the National Assessment of Educational Progress" [18, p. 29]. Further focus needs to be brought to this issue. Elementary education standards need to be increased in these areas by providing teachers with more effective ways to convey the material, and promote the subjects with more a more hands-on, innovative curriculum that engages the students' attention while the material is being taught.

There are programs being offered to high school students to increase their interest in the field of math and science, but not enough is being done in elementary education. To see a drastic increase in professional engineers and other technology related professions in the U.S., elementary education needs to be supplemented to perk interest in the subject matter at a young age. Many high school students already have it set in their mind that they "hate" math and/or science, and refuse to pursue any type of career than includes it. "Over the past 15 years, engineering education has witnessed a sharp increase in research aimed at the outcomes of academic success and persistence within engineering programs. Factors related to these outcomes are of particular interest with the declining interest in engineering among graduating high school students" [12]. These students may have not been exposed enough to the other aspects of having a career in technology or engineering, such as the creativity needed for design.

The National Action Council for Minorities in Engineering (NACME) was established in 1974 with the objective to catalyze strategies that would increase the participation of underrepresented minorities in engineering. The efforts of those involved in this organization have put a direct result on the population increase of minorities in engineering over the past few years already. They offer scholarships, special programs for pre-college, and college students, and have even published a collaborative book, "Standing Our Ground" that pronounces their views on issues that minorities faces and those they have overcome in the profession of engineering. Recently they have had an initiative to actively participate in increasing pre-college engineering education. They have yet to produce any programs, but a diverse type of peoples including those from government, corporate, education and institutional sectors have gathered to discuss and begin finding solutions of how to bridge elementary education in engineering with that provided at the high school and then college levels.

An excellent development by the NACME can be found on the website http://guidemenacme.org/guideme [19]. This site, produced by IBM and Web developer Enzyme Digital for NACME, is geared towards providing information to students and parents about engineering through surveys and brief articles. It offers information about what engineers do in a general sense, and what different types of engineers do more specifically. The site can also lead students and parents to links of colleges with engineering programs, and describes in detail how one would go about applying for a degree in engineering and what type of background admissions offices at colleges are looking for. Scholarship applications can also be filled out right at this site, which makes it easier for many students to do, and therefore make them more likely to apply. The site can really draw together a student and their parents/ guardians to making decisions about their future together. "According to NACME president and CEO, Dr. John Brooks Slaughter, the new Web site will help NACME, "produce more than 250,000 minority engineers in the next decade"" [13].

There are also many fellowship programs offered for students that are in the engineering field. The National Consortium for Graduate Degrees for Minorities in Engineering and

Sciences (GEM) is one group that offers such fellowships. This group focuses on helping underrepresented minorities at the graduate degree level, but also offers some programs for elementary education. There are other groups that provide opportunities at lower levels of education which include the Mexican American Engineers and Scientists, the National Association of Minority Engineering Program Administrators, NAMEPA, Inc., the National Coalition of Underrepresented Racial & Ethnic Groups in Engineering & Science, the National Society of Black Engineers (NSBE), the Society of Hispanic Engineers (SHPE), The Tutoring & Mentoring Component Program (TMC), and of course NACME. As it has been said "whether it's a roundtable for the automotive industry, a presentation for a professional society's conference or leveraging resources through relationships with organizations focused on K-12 or undergraduate technology student development, the core message is the same: increasing the numbers of underrepresented groups in engineering and science…. And students do have access to an extensive support network. Whether it's the university, other GEM Fellows, or the employer member, students can connect with people and resources to help them achieve" [14].

There is something just as concerning as the lack of general minorities representing the engineering and technology workforce in the United States. This is the lack of women participation in this occupation with only 6% of the engineering work force made up of women. What is even more disturbing however is that "Black women are 0.6% of the science, engineering, and technology workforce and Hispanic women 0.4%" [15, p. 257]. The deficient number of women in engineering has initiated studies across the country to find causes for this major gap between the representations of each gender. Civil rights movements in the 1960s and 1970s brought many groups to put forward extensive research on this topic. This ongoing research has led to the start of many helpful organizations and funding to help raise the number of women in the field.

At the American Society for Engineering Education convention in 1975 a report was presented which "summarized some of the strategies universities were using to increase the number of women in engineering, including appointing one or more individuals to coordinate the recruiting and counseling of women students" [16, p.1]. This began the creation of women support groups in the engineering field. In response to this analysis, programs such as Women in Engineering (WIE) and Women in Science and Engineering (WISE) were created to help promote engineering to the woman labor force. However these programs were not given the attention they deserved and the growth of women in the engineering workforce was a slow ascension. In the 1990s the WIE and WISE programs got a huge push in the right direction. The Women in Engineering Program and Advocates Network (WEPAN) was established which led to an "increased national awareness; and government, foundations, and industry funding, the number of formal WIE programs grew from 10 in 1990 to over 50 in 1999" [16, p.1].

Even with these organizations in place the acceptance of them in the female gender has been limited. With males still being the dominant gender in engineering including the education of engineering, women have a hard time finding fellow female role models to look up to in the field. Organizations have been working to create sources women can use where they can be educated on the past role of women in engineering. Websites have been formed committed to spreading the word that engineering is not just a male career choice, but can be chosen by women and has been chosen by women in the past with great success. These websites include, but are obviously not limited to The Field Museum's Women in Science website and the Women of NASA website. These "virtual mentors cannot replace the value of a female student being taught by or speaking face-to-face with a female scientist" [17, p. 79]. To help with this problem, the solution was decidedly focused in a different age range of women.

The increase of awareness and funding to promote women to enter engineering established in the college level is becoming more successful and now there is a need to direct attention towards younger ages. In 2000 the National Science Foundation reported, "women make up approximately half of the US population, 46% of the total workforce, yet only 23% of the scientists and engineers" [17, p. 79]. This new research has shown that the lack of women in the engineering field could be due to a lack of interest and promotion in the lower grades, where women are going through the difficult struggle of finding their place in the world and what type of person they will become. This is all done during the adolescent to teenage phases. In the elementary level, it is not very common for women to be encouraged to enter a field in science and engineering. Females still to this day are being told that there are certain career choices for females and certain career choices for males. These career choices for females do not include that of math and science backgrounds. This could be due to the lack of knowledgeable female elementary teachers in the United States. In the past females were never pushed to be advanced in mathematics and science. Many of these females went on to pursue the stereotypical educator career path. These females are now the educators of the next young female generation. The younger females are not getting the experience and education in math and science that they need due to the lack of experience and education in math and science of the person teaching them in these early years. By the time middle school is reached, "girls are seriously narrowing down their career choices and commonly do not include science as a future option" [17, p. 79].

Since their teachers are not taking the initiative to promote engineering education to the younger female age group, other organizations are stepping up to the task. One such organization is the Junior Girl Scouts of America. This group has developed its own proposal to promote the sciences in their organization. Over the years more than a dozen badges have been added relating to scientific and technological subjects. In this manner, the science and technology education deficiency being seen in the school system is now being compensated by the Girl Scouts organization. The requirements for these badges have been carefully selected in order to promote the field as efficient as possible. Many hands-on activities are designed in order to make the material "more interesting to students and provide girls an opportunity to obtain self-confidence in their ability to do science" [17, p. 80].

However, even with the encouragement of the organization to pursue the new additions to the Girl Scout achievements, these new badges were not being earned as often as badges in the other categories. One group took notice of this and decided to do something about it. They were a group in the Pennsylvania State University Delaware Country campus in Media who were participating in a service learning program. Service learning programs are set up by colleges across the nation to involve their students in the solving of real world problems. These groups are organized and given a problem in the community in which they need to create a possible solution for and try to implement their solution in a relevant and meaningful way. At the Penn State campus, their service learning program was directed towards the lack of women in the science and engineering fields. After extensive research on this topic they decided to put their focus into assisting the Junior Girl Scouts of America in the integration of science and engineering concepts into their badge program. The program took in 60 Junior Girl Scouts and on a Saturday afternoon the college students began their work to assist these Junior Girl Scouts in various activities to attain their science and technology badges [17].

Before the girls returned home that evening, the girls took surveys at the beginning of the afternoon and then another at the end of the afternoon, which showed that the day had been success. At the beginning of the afternoon a survey was conducted over the girls which resulted in 7% of the girls answering they really liked science, 53% of the girls answering they liked science, 33% of the girls saying that science was okay, and 7 % of the girls saying they hated science. At the end of the afternoon there was a change in the opinions of many of those 60 Junior Girl Scouts. In a survey taken right before the girls went home, 67% of the girls reported they liked science a lot more than before that day, 27% of the girls reported they liked science a little more, 7% said they feel the same about science, and none of the girls said they disliked science more because of their experiences in the program. This program is a good source of importance and effectiveness of education of science and engineering concepts to women at an early age. Just in one afternoon a majority of a group of females had their opinions drastically changed about the science and technology field. This process being expanded to a nation wide scale could be what the nation needs in positively promoting science and technology education for women [17].

# 4. Goals and Methods

In order to successfully complete the problem WPI presented to the National Science Foundation, the IQP students working on the PIEE Project had to complete several tasks in the production of several items for the Grades 4-6 of the Worcester Public Schools. These items include:

- A set of uniformly formatted binders (one binder per grade) with all lesson plans and supplementary materials in successive order, with relevant bibliographies. Both Midland Street School and Elm Park Community School received a copy of the binders per grade.
- Engineering bins which included all of the materials necessary to carry out each lesson in the developed curriculum.
- Flexible lessons that can be easily altered to parallel with the changes that will occur with the evolution of the field of technology and engineering.
- Organized, uniformly formatted lessons that can be easily accessed for the teachers.
- A spreadsheet of all lessons ordered by grade and categorized by their WPS Benchmarks and MA Frameworks. A copy of this spreadsheet is included in each of the binders.

In the previous years of the PIEE project, drafts of most of the lessons for engineering concepts in grades 4-6 had been created. In this final year these lessons were finalized and all supplementary materials and missing lessons were created. The PIEE members had established a number of tasks that would create a sufficient curriculum of engineering concepts that would be easy to use by teachers and students. This included the creation of large engineering bins with the materials for all lessons to assist the instructor in the lesson's activities. Evaluations were prepared to assess the lessons and kits, as well as the student's ability to grasp the material presented. The lessons and kits were created to be flexible with the changes that will occur due to the dynamic nature of technology and engineering. A knowledge-sharing website which will be accessible to all MA educators will be created by the PIEE integration team from the well organized and uniformly formatted files of each lesson by unit within each grade. This website will include copies of all the finalized lessons which follow the relevant MA frameworks and WPS benchmarks. It will include the spreadsheet of all the lessons developed in order to provide an easy to follow outline for teachers which acts as a guide for access to the lessons.

The newly created lesson plans were incorporated with the existing lessons plans and have been evaluated and critiqued. Lessons from previous years were edited and then new lessons were created to fill in any gaps. All lesson plans were formatted and brought up to date with current PIEE standards. The newly formatted lesson plans were taken to the Worcester Public Schools to be taught to the students as trial runs and were evaluated on their effectiveness. This allowed us to obtain knowledge of the student's progress by direct contact. It helped teachers put a face to the project, and feel more comfortable during the implementation of the lessons and provided engineering role models for the students.

Once all the units were evaluated and finalized, they were compiled with all relevant source information into binders which have been dispersed to all participating Worcester Public Schools grades 4-6. They included a table of contents and sections to separate each unit within the binder. At the beginning of each unit within each grade's binder there is a document with a brief summary of all the lessons included in the section. This includes relevant MA frameworks and WPS benchmarks, a summary of the actual lesson, the time the lesson takes to complete, any background information needed, and key words from each lesson. Two sets of binders were created for each grade, one for Elm Park Community School, and the other for Midland Street School. All of the lessons within the binders include any handouts needed, and were placed in sheet protectors to make it easier for the teacher to pull out what needs to be copied for the students. All of the lessons are formatted the same to make the binder more uniform, and easy to follow. The lesson binder is essentially for the teachers so they can see how each lesson supports the goal of teaching students how engineers interact in society, and the importance of their role in providing a safer environment for society. The information contained in these binders will eventually become available both electronically on the WPI website and a hard copy archived for future review.

These binders were only the first step in implementing engineering concepts into the curriculum of the Worcester Public Schools. Teachers were also supplied additional resources for certain lesson plans to successfully introduce engineering concepts and activities. To provide these additional resources to the teachers, large engineering bins were created. These bins include an inventory of all the materials within a grade's curriculum along with sufficient resources for the entire class' participation. The fully functional, ready-to-use bins will be distributed to all the participating Worcester Public Schools. The purpose of preparing the bins was to have all products needed for these activities on hand for teachers to use. The bins include all of the items needed for each activity. The components of the bins were packaged into Tupperware containers and plastic bags marked with the lessons the material is used for. The bins include enough supplies for a classroom of about thirty children. The materials list is formatted into a table with three columns; item, approximate price and vendor where the teacher may purchase more to replenish the bin's products. The prices of the items are listed with the unit price of the product and price of the actual purchase to show how much you need to spend on each student. The list also includes the total prices spent on consumable and non-consumable items. The bins are an essential part of the lessons because they provide physical items that students may use to carry out the engineering design process and to see how engineers can help society.

**Figure 1: 6th grade engineering supply bins**

These supplementary materials will need to be revised and updated over the upcoming years at the educator's discretion. To assist in this process, evaluation forms have been created to help teachers assess the functionality of the materials and the effectiveness of the lesson plans. The feedback from the evaluations of the lesson plans and kits helped us get a better idea of how effective the lessons were in the classroom. Having the teachers fill these with their comments provided us more information on how easy or hard the lesson was for the teacher to use, and also how the children were able to perform from a first hand source. An example of an assessment sheet can be viewed in *Appendix 1*: Evaluation Sheet. The ultimate goal of each lesson was to meet the WPS benchmarks. The assessment sheets allowed us to review the lesson and make changes to be sure all lessons were easy to follow. This also provided an effective way of finalizing each lesson. The assessment sheets decreased the "trouble-shooting tips" and made the lessons more clear and concise to follow. They also helped to show how well the engineering design process was used to solve the problems presented in the class activities.

The creation of lessons organized into binders, bins to assist teachers, and evaluations that the PIEE 4-6 team developed for the teachers of the WPS are intended to provide the students with materials that will effectively show them the role of engineers in society. The benchmarks have been related to "real life" applications and how engineers are involved in them. The engineering design process, as seen in *Appendix 2*: Engineering Design Process is presented as a tool to complete most of the activities in the lessons. All problems that engineers face use this process to come up with the best possible solution. The process is brought down to a level that is realistic for the students. For example, their research may be limited to simply using the knowledge they have already if computers and/or a library are not accessible. The students must learn how to follow the steps of the design process in order to complete the activities. For example, in the unit on "Understanding the Earth", in grade 6, there is an activity to create a miniature volcano. The students not only create the volcano and actually see how it works, but also build a "village" around the base of the volcano to see how it affects the people. The lesson explains that an engineer's job may be to estimate the amount of devastation the volcano would have on the "village" in order to protect the people. The students must use the engineering design process to develop and implement their ideas of how an engineer would actually try to help and protect those residing around the volcano. By following the steps of the process, they were able to implement ways to save the people of the "village".

The bins, lesson binders, and assessment sheets were all tools that the members of the PIEE project used to shape the curriculum geared toward how engineers are involved in society.

They made all the necessary items and tools needed to implement these ideas in the classroom easy to follow and use. Without these three tools, the lessons would not be organized enough to be passed on to future classrooms.

To provide a comprehensible and manageable database containing all the resources created by the participants in the PIEE program, all the grades 4-6 lesson plans and supplementary materials were organized into a single spreadsheet categorized by what WPS benchmarks and MA frameworks they fulfilled. This inventory was included in each of the binders and will also be posted electronically on a knowledge-sharing website accessible to all MA educators. This information will hopefully provide a simplistic resource for reviewing all the possible materials for teaching each of the units and the benchmarks they hit. In addition, this resource provides a foundation upon which other groups can follow and expand their implementation of engineering education.

The main motivation for the individuals working with the PIEE program was to be involved with the development of young children and to help them to attain the most knowledge in the field of engineering as possible. In order to evaluate this progress the team had to create a body of practices, procedures, and rules (methodology) in order to apply these standards and assess the progress of the project and more importantly the children's progress. The clear methodology set up allowed us to become more critical of areas in a constructive manner by organizing all of the deliverables.

The solution to the problem of improving engineering education and awareness in the elementary grades four through six can be basically summed up in two steps. Although this is an over simplified description of the project, these steps consist of creating a supplementary engineering curriculum and the means to carry on, modify, and improve this curriculum for future generations. The methodology chosen for this project, as stated previously, adequately accomplished all of the goals deemed necessary to make this project a success. The execution of action taken is relevant to the completion of this project for three main reasons; it provided the students with a familiar learning method to help promote engineering education, a simplistic method for instructors to introduce and teach engineering concepts, and a durable engineering curriculum with room for modification and improvement.

The approach taken to produce an engineering curriculum for grades 4-6 was chosen because it was consistent and addressed the problem proposed to this PIEE team directly. This

PIEE team needed to develop a curriculum that would relate engineering to students in grades four through six. Since other science units were already being taught in the classroom, it seemed logical to make the new engineering units supplementary these science units. This allowed instructors to easily introduce engineering concepts and skills that fit seamlessly with what the students were already learning. This gave the students a familiar method of learning an unfamiliar engineering curriculum.

There was also a need to make the curriculum adaptable, improvable, and able to be carried on even after the completion of the project. The methods chosen to make this a reality are relevant because they solved all of these issues and allowed us to complete all of the project goals by successfully implementing engineering in grades four through six. Through the use of kits, binders and eventually databases a means for instructors to carry on the curriculum for future generations was provided. Also, the products from completing the given task along with evaluations provided instructors an easy way to adapt and improve the curriculum framework provided.

The goals for the undergraduate students doing their IQP were to create a formal curriculum on engineering concepts for grades 4-6 and prepare the faculty and students in the Worcester Public Schools for the implementation of the new curriculum. The team of four students and two fellows worked directly in the classrooms with grades 4-6 to develop a solid curriculum and created ready-to-use engineering bins with the materials for ach lesson plan. Time was spent revising the existing lesson plans, filling in the gaps in the curriculum with new own lesson plans, creating the bins and binders to help aid teachers in their lessons, and preparing the 4-6 grade teachers with direction of how to teach this new curriculum comfortably and efficiently.

# 5. Implementation

Our IQP team's methodology for the PIEE project, grades four through six, consisted of the completing the main deliverable, the lesson plans, necessary to make the program a success. To produce these lessons, each of the four members of the team was partitioned by the grade level they would be focusing on. Much of the work for each grade level was similar in some manners and each team member followed the same basic guidelines. The process of producing these lessons can be broken down into four phases; organizing existing materials, modifying/improving the curriculum, formatting, and finalizing the final products.

## 5.1 Organization

The first step of the process was the organization of the material that had been created over the past two years of the project. Each grade was provided a majority of the lessons that are included in this year's final draft of the PIEE project from a CD-ROM which included all of the work from the past two years of the PIEE project. This information, in some cases, was not organized into a clear format and it was hard to decipher what information belonged to what lessons or to what folder. This CD was, however, broken down into three sections, one for each grade level.

We dispersed this information according to who was working with each grade level, and continued from there to review all the material on the CD. The information was organized into sections and it was decided what materials would be kept. An estimate was made as to what needed the most work and how to schedule our time.

## 5.2 Modification of the Lessons

The next aspect of completing the finalized curriculum was to modify the existing lesson plans according to a set of criteria. The essential guidelines for the lessons were set by the WPS benchmarks and MA frameworks, and had to be consulted in order to produce effective materials. It was necessary to follow these resources in order to provide a comprehensible set of lessons that would teach all key concepts clearly and effectively. The benchmarks are categorized into five main sections. They are Skills of Inquiry, Earth/Space Science, Life Science, Physical Science, and Technology/Engineering.

It was a goal for each grade to incorporate as many of the benchmarks as possible in the curriculum that was being developed. Some of the existing lessons addressed some of these benchmarks, so the focus of this year's team initially was to re-evaluate the lessons to determine if the benchmarks that were said to be met were effectively covered. Once the benchmarks were clarified in each of the lessons, the full list of benchmarks was referenced to identify which still needed to be incorporated into the lessons.

The benchmarks that had not been met by the existing lessons were evaluated in order to establish how to cover the topics that needed to be presented in the lessons. It was decided that some of the benchmarks could be incorporated into existing lessons. However, not all benchmarks were met in the existing lessons at each grade level, so some new lessons needed to be created depending on the each grade level team's decision. The decision making process used by the individuals working in the separate grade level teams is discussed in further detail in the following sections labeled according to grade level.

After each individual finished evaluating the benchmarks and organizing the lesson plans for their grade's curriculum, the lessons were reviewed and modified. These modifications included deciding on supplemental materials and information, fixing grammatical errors, and including more specifications. The team made sure that the lesson made sense in general, seemed feasible for the students to enjoy, and that a teacher could understand it easily in order to execute it efficiently. Some lessons were added to, and some were condensed during this process. We went through this process based on our own opinions formulated by readings on the topic of teaching engineering education and grade specific literature, our background as engineers, general knowledge, discussions with our grade advisors, and evaluations.

Evaluations of the lesson plans created were an important aspect for each grade level. These evaluations came in two forms. The first type of evaluation was from visiting the classrooms; the second were direct, written, evaluations collected from the teachers, which were complicated by issues that will be discussed in more detail farther on.

The classroom visits were completed by both the IQP students and by the graduate advisors, and were direct observation of the lessons performed in the participating classrooms. These visits served a variety of purposes, most importantly the lessons could be viewed and it could be determined if changes needed to be made in order to improve them. An important observation that came about from these visits was that the students of two different schools, Midland and Elm Park, exhibited different learning challenges and abilities. This drove the team to incorporate different levels of lesson instructions and suggestions, so that teachers would have a choice depending on which they felt would be more beneficial to the students. This interaction with the instructors and students also helped us determine what aspects of the lessons may need alteration, such as materials, supplement information, and teaching strategies. The interaction with the students and teachers also served other functions, including dispelling myths about engineering and about how engineers are supposed to act and educating instructors of interesting information about current engineering.

The second form of evaluations was a survey where the instructors could evaluate the lessons they performed in their classrooms directly, giving suggestions on the changes they would like to see. However, there was not a good success rate in having the teachers fill out the forms or getting the information back to the team in enough time to be effective in the modification process. Some information was received from the participating instructors and was helpful in making changes but this method ended up not playing as big a role as was first expected.

Once the evaluation process was completed and relevant information was gathered, the modifications and improvements were incorporated to each lesson by the individuals working on the separate grades. After the changes were in place the next phase of the project was to put the developed lessons into a uniform format.

## 5.3 Formatting

To improve the effectiveness of the lesson plans that will be implemented into the Worcester Public Schools curriculum all of the lessons created had to adhere to a uniform format. The PIEE project leaders decided upon this format, and a lesson template was followed while making each lesson. The template format created uniformity among all of the lessons within each unit. This uniformity makes it easier for an instructor to simply pick up any lesson plan, read through it, and apply it to the classroom. The goal was to make it as convenient as possible for the teacher to follow the lessons that were created, so that they can be used for years to come. The lessons that were created were meant to be supplemental activities that pertain to the science and math material being studied in class. All of the activities needed to be well organized to run smoothly in a timely fashion. The Worcester Public School system has stringent times that they are allotted to teach certain subjects due to the Massachusetts Comprehensive Assessment System (MCAS) testing. Additional lessons are difficult to fit into their schedules, so it is important to make them straightforward for the teachers to understand quickly and for each lesson to include the benchmarks of the WPS.

The formatting process can be broken down into three basic sections, which were organizing the gathered material, creating new material if necessary, and then clarifying the finished product. Most of the existing lessons had already been organized into specific sections over the past couple years. This made it easier to put the information into the new format. However, some of the lesson plans were not completely organized and the information necessary for the new format had to be extracted from them and added to.

Once the information from the existing lesson plans was organized and incorporated into the new format, the sections that had missing information were filled. Some of this information had to be created based off of the existing information from the old lesson plans, but other information had to be researched. Examples of the minor types of information that needed to be created for some of the lessons are key words, vocabulary definitions, definitions of the Worcester benchmarks, required background information to perform the lessons, essential questions, and suggestions for the assessment/evaluation of the students.

There were some units that needed to be created for all of the lesson plans. These included a material list and a unit summary. The material list is a table that contains a revised list of all the materials necessary to complete the lesson, amount needed for each student or teams of students and suggestions on were they could be purchased or found. The unit page gives a brief summary of the unit's corresponding lessons and all the key concepts in the unit, and also followed specific format. This allows teachers to easily access lessons that pertain to the core science studies that are current in their classroom. This document also allows teachers to see what is available for them in order to make a faster, easier decision on what exercise would be best for the time they have time available to teach an engineering related session.

After all the information was incorporated into the new format and all the gaps were filled, the lessons were then reviewed and any final changes were made to help clarify the information it contained. When a finalized copy was made of the lesson with all minor changes, it was posted online as a final draft ready to be reviewed by the 'Curriculum Integration Team'.

## 5.4 Finalizing

The finalized deliverables for this project included a uniformly formatted engineering curriculum to be implemented in grades four through six, and also the means of delivering and storing this curriculum at the participating schools. This also includes the creation and organization of supplemental material kits to accompany the curriculum. The development and assessment of our delivery method and material kits was discussed throughout the entirety of the project, but the final step of the project was to complete these aspects and deliver them to the schools.

Once the curriculum had been modified and formatted and was at its final stage it was decided that the best mean to deliver the package of lessons and units to the participating schools would be to place hard copies of lessons in binders. The binders provided organization and protected the lessons but at the same time allowed instructors the freedom to remove sections for viewing if necessary. A final format for these binders was discussed pertaining to organization, look, and cost. The final format was decided on and once the materials were purchased this step was quickly completed. Two three ring binders were filled with all the lessons and unit summaries, marked clearly by unit for each of the grades. A Table of Contents was included along with over-head projections for certain handouts. Each page was placed into sheet protectors to make the binders more long-lasting.

The supplemental material kits were more difficult, and took on two phases throughout the project. At first, small individual kits that were brought into the classroom during the classroom visits/lesson evaluations. These kits consisted of everything necessary to complete the accompanying lessons, which included craft supplies, worksheets, building materials, and in some cases materials that had been produced by the IQP team, i.e. volcanoes, two maglev tracks, or demonstrations. However, issues began to arise with the volume of kits being brought into the classrooms and this created problems with our overall goals for the kits, which were to be self sufficient, storable, and easily refillable.

**Figure 2: Inside of engineering supply bin**

The second phase for the kits was a new design developed to make reaching our goals more accessible. It was decided that instead of creating smaller kits for each lesson, one large "engineering bin" would be created for each grade level. The large bin would include all of the materials necessary to complete every lesson in all of the units for the specific grade. We felt that this design would be easier for the instructors to manage and would promote its use and the replacement of materials it contained as they ran out in future years.

To ensure the success of these kits other information was developed to be used in conjunction with the kits. Each large “engineering bin” also includes a detailed inventory list. This list not only contains everything inside the kits and the amount of each object, but also shows rough estimates on the price of each material and suggestions on where each could be purchased.

The completion of the uniform engineering curriculum organized into uniform binders and the supplemental materials into large engineering bins was the final step for the IQP team in the PIEE project. Once this was completed, the materials were handed over to the appropriate schools and grade levels.

## 5.5 Detailed Modifications

During the process of modifying the curriculum for each of the separate grade levels there were differences in how each team member made their changes and how decisions were made about the lessons. The following sections are the specific details for the organization, modification, improvement, and formatting processes for each grades’ team.

### 5.5.1 Fourth Grade

The fourth grade team for the final year of the PIEE project, 2005-2006, was composed of one fellow, Jen Gray, and one IQP student Alex Christiansen. From the CD created over the past two years of the project, the folder for fourth grade was reviewed and it was decided that the curriculum would be broken down into eight units. The units were *(A) Introduction to Engineering, (B) Small Structures, (C) Energy, (D) Sounds and Waves, (E) Life Science, (F) Electricity, (G) Simple Machines,* and *(H) Weather*.

The IQP student Alex Christiansen left WPI and dropped out of the project before its completion. He had only done minimal work, while participating in the project and the rest of his work was left up to Jen Gray, his fellow. The work that Alex had done before leaving the project was he formatted the following units, *(A) Introduction to Engineering, (C) Energy Unit and (D) Sounds and Waves*. He also began the formatting process for Unit H: *Weather* but never finished, only completing the first draft. He also helped to create a definition list for Unit C and a first draft of a materials list for the engineering bins. After he left the project, the rest of the material for the grade four lessons was handed over to Jen Gray. She took on his responsibilities and due to workload from other responsibilities could not get the fourth grade work finalized for the completion of the project for the IQP team.

### 5.5.2 Fifth Grade

The fifth grade team for the final year of the PIEE project, 2005-2006, was composed of one fellow, Leena Razzaq, and one IQP student Tom Hayes. From the CD created over the past two years of the project, the folder for fifth grade was reviewed and it was decided that the curriculum would be broken down into ten units, which had been used the past year with success. The units were *(A) Introduction to Engineering, (B) Shadows and Seasons, (C) Erosion, (D) Habitats and Environments, (E) Simple and Complex Machines, (F) Light and Color, (G) Sound, (H) Magnetism, (I) Space Probes, and (J) Structures*. Each of the units had existing lesson plans, which needed to be modified, updated, and formatted. However, there was also the need to create new lessons to fill gaps in the curriculum. Once the lessons were decided upon they were reviewed and modified according to the general modification process stated above and then formatted. The following is a unit-by-unit, lesson-by-lesson description of the modifications made to the lesson plans and the work done by the fifth grade team.

*Unit A: Introduction to Engineering*

This unit consists of two lessons; the first lesson is *Introduction to the Design Process*. This lesson was reviewed and evaluated by the fellow assigned to 5$^{th}$ grade, Leena Razzaq, as an example of the correct format. She made all the primary changes. Tom's work was to review the changes that had made and then put it into the correct format. The second lesson in this unit was titled *Make an Antacid Rocket*. It was an existing lesson plan that was originally not part of the curriculum that was planned, but at the suggestion of one of the teachers in the program, the lesson was added. Upon viewing this lesson performed in the classroom, changes were made to the instructions to help the students better understand and execute the lesson. Instead of performing their experiments and then recording what materials they used, it made more sense for them to fill out the materials they would use before they began their experiments. This allowed the students to focus more of their attention on what substances were reacting instead of just throwing materials together to make the rocket work.

*Unit B: Shadows and Seasons*

The lesson in Unit B, *Sundial Wristwatch*, was evaluated in the classroom. Based on observations made during the implementation of the lesson and evaluations from the instructors changes were made to better include engineering. A new brainstorming section was added to help re-enforce the engineering concept that thinking about a problem and forming a plan is essential before work can be done. A worksheet was then added to the lesson to allow the students to form a more detailed plan and draw sketches of their brainstorming session. The suggestion included was to allow instructors to have the students try and design their own wristwatches before using the instructions.

*Unit C: Erosion*

This unit contained only one lesson plan, *Preventing Erosion with the Engineering Design Process*, which was evaluated and from the observations it was determined that the lesson should be broken down into two sessions. This was decided in order to give students more time to brainstorm and design their retaining wall before building the model they would be testing. This extra session was also added to allow the instructor more time to review erosion concepts learned by the students in their normal science lessons with the participating students. Once the lesson was evaluated in the classroom it was determined that a new water delivery system should be included with the materials to better simulate the erosion process. The dirt used also presented a problem and did not simulate the erosion process as accurately as planned. Finer dirt, instead of potter's dirt, may solve the issue and cause a better flow under classroom conditions. Further tests would help to establish a type of dirt that will produce the right conditions, which there was not time to do.

*Unit D: Habitats and Environments*

The only lesson in Unit D is the *Biome Laboratory*. This lesson was lacking in its ability to show a connection between predator and prey and how all the organisms in a specific biome are linked and depend on each other for survival. To remedy this issue the lesson was modified to contain informational worksheets and a new section that covers food chains and the relation of predator and prey on survival. This worksheet was added to test the student's knowledge on the food chain of the biome they were assigned to create so that they would have to do research in this area. An information sheet was also provided to give instructors examples of food chains for all of the biomes taught in the classroom. Once the lesson was evaluated in the classroom, it was determined that the lesson needed to be broken down into two sessions that would allow students more time to research before they started building their biomes. However, this proved to still be too short of a time period. So suggestions were added to the lesson to assign students with some of the research for homework and to have a separate session devoted to having to students present their projects.

**Figure 3: Biomes designed by the Students**

*Unit E: Simple and Complex Machines*

There were three lessons in this unit, *Which Simple Machine Should I Use*?, *Make a Pulley System*, and *Design A Complex Machine*. The first lesson, *Which Simple Machine Should I Use*?, was very basic and did not need much modification other than being formatted. After evaluation in the classroom it was determined that no further changes needed to be made. The second lesson, *Make a Pulley System*, was modified to include a separate brainstorming section. This allows students to try and develop ways to design their own pulley systems out of household materials instead of just following directions. This addition helped re-enforce the creative process of engineering design and planning before building. The third lesson in this unit, *Design a Complex Machine*, was modified to include a video created by Arthur Ganson, which shows the students how simple machines can be combined into a large very complicated machine that, ironically, does a very simple task. A worksheet was also added to allow students to communicate the complex machine designs that they brainstormed by making sketches and writing instructions.

*Unit F: Light and Color*

Unit F was planned to only contain one lesson, *Up Periscope*. This lesson was modified to allow students more freedom in designing their own periscope out of available materials, instead of just having them follow the direction sheet included. A brainstorming worksheet was included to allow students to record their ideas if they are able to come up with their own designs. This helps to re-enforce the creative process of engineering design and also that it is essential to plan before starting the manufacturing of a concept. The 5th grade fellow, Leena Razzaq, created a second lesson, *Build a Spectrometer*. However, upon evaluation of this lesson in the classroom it was decided that this lesson was too difficult and that it would cost too much money to replenish the supplies.

**Figure 4: Periscopes Built by the Students**

*Unit G: Sound*

This unit consists of two lessons, *Make a Musical Instrument* and *String Telephones*. The first lesson, *Make a Musical Instrument*, was modified to incorporate more WPS benchmarks, which would increase its teaching potential. Sections were added to show students how animals use vibrations to produce sounds and then this was compared to how musical instruments make sound by creating vibrations. This showed the students how mechanical systems emulate natural systems and a link between form and function. The lesson was also broken into two sessions so that the instructor would be able to adequately teach key concepts related to sound and perform informative sound demonstrations, while also allowing students more time to brainstorm and design their instruments before they started building them. The second lesson, *String Telephones*, was an addition to the curriculum and was created from scratch. It was

**Figure 5: Musical Instruments Designed By Each School**

decided that the sound unit was not adequately covered by only one lesson and that other key concepts of sound from the normal science units already being taught in the classroom could be incorporated into engineering. This lesson was created to show how sound moves through different mediums and also teaches engineering concepts by having students brainstorm, design, and build their own string telephone. A worksheet was then added to allow the students to perform experiments on the telephone they designed so that they could gather qualitative data on the transfer of sound.

*Unit H: Magnetism*

Unit H, consisted of two lessons, *Maglev: Its Repulsive!* and *Beachcombing With Magnets*. The first lesson *Beachcombing With Magnets* was a late addition to the curriculum but was it decided that it was a good engineering lesson and met enough benchmarks to be relevant. This lesson had been used over past years and after evaluation in the classroom it was determined that it did not need to be modified heavily. The second lesson *Maglev: Its Repulsive!* was modified into to include two sessions that allowed the students more time to design their maglev cars, instead of being rushed into the building process. This also allows the instructor to spend more time teaching the concepts related to magnets and giving the demonstrations included with the lesson plan. Also, two maglev tracks needed to be redesigned and built for this lesson based on the criteria that they could be easily stored in a small room. Two new designs were evaluated and it was decided that the tracks would be made of wood and broken down in three two-foot sections per each track. These sections would link together using interlocking pieces and would consist of a single track down the middle made of wood with a track of magnets next it along each side. The supplies for these tracks were ordered and both tracks were built by the IQP team for fifth grade.

**Figure 6: Examples of Filtering Devices Built by the Students**

**Figure 7: The maglev track with cars designed by the students from both schools**

*Unit I: Space Probes*

The lesson in Unit I, *Design a Space Probe*, was modified into two sessions to allow students more time to research their problem and adequately learn the key concepts. Suggestions were also added that allow the student to build the space probe they designed out of craft materials.

*Unit J: Structures*

The lesson in Unit J, *The Sky's the Limit*, was modified into two sessions to allow students more time to research their problem and adequately learn the key concepts. Suggestions were added to help improve the quality of the structures being built and also on ways to have the students redesign the original structures. There was also a new section added that suggested that this lesson could be turned into a competition, allowing teams to build the largest structure they can but at the same time still adhering to the specific rules assigned.

## 5.5.3 Sixth Grade

The sixth grade team for the final year of the PIEE project, 2005-2006, has two fellows and two students. The fellows are Jen Gray and Leena Razzaq, who are current graduate students attending WPI. The IQP students are Rachael Buteau and Mark Meko, whom are currently enrolled as juniors in the WPI undergraduate program. Rachael is majoring in Biomedical Engineering, and Mark is majoring in Mathematical Sciences, and is also pursuing a minor in Computer Science.

After careful evaluation of the benchmarks laid out in the Worcester Public School Curriculum, the team broke them down into units. The sixth grade PIEE project includes seven units which are as follows, *(A) Introduction to Engineering, (B) Understanding the Earth, (C) Cells and Heredity, (D) Temperature, (E) Atoms and Molecules, (F) Measurements, and (G) Force*s. These seven units address numerous benchmarks of the Worcester Public Schools for science education in the sixth grade.

On the CD-ROM provided to the PIEE teams, the 6th was given a folder specifically pertaining to lessons for their grade. This folder was not ultimately organized and had sub-folders within it, which pertained to two participating schools, Midland Street School, and Elm Park Community School. There were also folders that contained lessons from the first year and were in PDF format. This CD-ROM was used each time a new unit was addressed. The folders were searched for any existing lessons that could be incorporated into the unit being finalized. Once all files that could possibly relate to the topic were found, they were evaluated in order to "weed out" any incomplete or insufficient lessons. We found that many of the lessons from the first year of the project were not used in the finalized units. There were two major factors used to make the decision whether or not to include a lesson. First, the information in the lessons was read through and assessed for clarity. If the lesson was incomplete or some areas were not explained well, our team decided whether there was sufficient material for us to complete the lesson ourselves. Once we decided which lessons were ready for formatting we then looked at which benchmarks were met in the lessons. If there were lessons that did not meet many benchmarks or the benchmarks were already met in the other lessons, they were removed in order to keep repetition and irrelevance out of the lessons.

Once the lessons had been put into the correct format the content was edited. These drafts were taken into the classrooms to be evaluated and finalized. The two schools we visited this year are Midland Street School and Elm Park Community School (EPCS). The teachers are Cecelia Gray and, Lisa Quinn and Mrs. Dennison, respectively. Lisa Quinn was on maternity leave for three months, which began the week before Thanksgiving, and had a temporary substitute teacher named Sarah Gross who fortunately cooperated with us so the PIEE program continued through her leave of absence.

Throughout the project the 6$^{th}$ grade team has worked rigorously to finalize the lessons and units in the curriculum. This process was similar to the process used by each team member for the three separate grades but the specific details of our work varied from the other grades. The following is a listing of each unit along with a summary of the work done by the 6$^{th}$ grade team.

*Unit A: Introduction to Engineering*

In the Introduction to Engineering unit, we have incorporated five lessons which include *Introduction to Engineering, What is Engineering, and What Types of Things Do Engineering Create?, Introductory Brainstorming Lesson,* and *Brainstorming and Solving Engineering Problems with a Decision, Brainstorming: Picture This*. Not all of these lessons address the WPS benchmarks, but each provides a good foundation for students to understand who and what engineers are responsible for in society. The WPS benchmarks that are met in the lessons fall in the Engineering/Technology section of the WPS Curriculum. We were tempted to remove some of the lessons from this unit, but decided against it because we felt that each one of them provided useful information about engineers, and promoted the profession by making it look "fun". Many sixth grade students are unaware of the amount of work engineering provides for communities, and are impressed with the variety of careers it can lead to. The lessons also range in difficulty somewhat, so one teacher may choose a more difficult lesson for their classroom, while another may choose one that is a bit easier for the students to handle. Some of the lessons simply discuss different types of engineers, and connect each type of engineer with specific examples of tools and projects each would use. Other lessons focus on the engineering design process, especially the step pf brainstorming. It is stressed in many lessons throughout the units that this is a crucial part of the engineering design process, and that all ideas are good during this phase, no matter how bizarre they may seem at first.

*Unit B: Understanding the Earth*

This unit includes five lessons, which include, *The Earth's Layers*, *Voila Volcano*, *The Earth is a Plateful*, *Earth Clock*, and *Earthquakes*. All of these lessons obviously correlate to the physical science category of the WPS benchmarks. Leena was the one to put them into the correct format, but Mark and Rachael then took those copies of lessons and thoroughly reviewed content and grammar. Many changes were made to these lessons. For example, the lesson on volcanoes originally had the students create volcanoes as a first activity, and then design and build a village that would save people residing at the base of a volcano. We made the lesson focus more on the creation of the village, and broke it up for the students to follow the steps of the design process in order to create a village that would survive an eruption. After observing this lesson in a classroom at Elm Park Community School, the lesson ran very smoothly and it was decided that the changes should be kept. Most of the lessons in this unit were ones that we have evaluated in the classrooms. The only one we have not seen in the classroom is *The Earth is Plateful*.

**Figure 8: Volcano from Viola! Volcano lesson**

*Unit C: Cells and Heredity*

This is the one unit that Mark and Rachael have not worked on during the project. Jen took on the responsibility of completing this unit which includes the seven lessons: *Introduction to Cell Organelles, Design a Cell Travel Brochure, Proportional Cell, 3D Cell (Edible), 3-D Cell (Not Edible), Cell Analogy*, and *DNA Codes*. They have however seen one of the lessons in the classroom. They saw students learn what DNA coding is, and actually create messages and decode them among their peers. This exercise was somewhat lengthy, but the students were able to understand and see how DNA coding works. When verbally evaluating the lesson with the teacher, a decision to create a restriction on the length of the message was made. We also noticed that there were some mistakes made in the decoding of messages, so we decided it should be added into the lesson that these errors represent a mutation.


**Figure 9: Cell created in 3-D Cell (Not Edible) lesson by 6th grade Midland student**

*Unit D: Temperature*

There are only three lessons in this unit which include *Convection, Conduction,* and *Temperature and Heat Transfer*. We think it is better to have fewer lessons in here than include numerous lessons, because the benchmarks they must meet are very specific and only select types of activities could be used. The concepts of convection and conduction are taught with the most focus. The students learn about these concepts through basic observations of simple experiments. For example, the convection experiment has three ice cubes, colored with food coloring, and each placed in three different temperature bowls of water. The students observe what happens when the ice cubes are put into the different temperature waters in order to conceptually understand what convection is.

*Unit E: Atoms and Molecules*

This is the unit that the IQP students had to do from scratch. Although there are only two lessons, they are very thorough and hit all of the benchmarks that are associated with the science and include *Modeling Molecules: Atoms and Molecules* and *Conserving Mass: Concept of Conservation of Mass.* The students need to understand conceptually what an atom is at this age. The benchmarks to meet ranged from understanding the physical properties of atoms to how they bond to form molecules that make up everything we encounter in the world to actually witnessing chemical reactions to show how mass is conserved. The two lessons have the students participating in various activities. Various sized colored Styrofoam balls are used to represent different atoms, e.g. hydrogen, oxygen, nitrogen, etc. The size of the ball depends on the atomic number of the atom. Using toothpicks as bonds the students build a variety of compounds to show how atoms combine in a number of ways to create the matter that makes up the world we live in. As a supplementary activity the students will be brainstorming a molecule of their own creation using any and as many of the atoms given. The students develop a purpose and structure of their molecules and present them to the class. For the benchmark regarding the principle of conservation of mass we created a lesson, which has the students witness the chemical reaction of an alka seltzer tab and water in a closed system. The system consists of a graduated cylinder or test tube with a balloon covering the top to keep the system contained. This introduces the student to key concepts in engineering like conservation of mass.

*Unit F: Measurements*

The benchmarks for this unit included understanding the concept of mass, weight, volume, and density and tools used for making measurements. For this unit we have formatted four lessons which include *Chairs Up!, Understanding Scale and Measurement,* and *Density and*

*Hydrometers*. The lessons put an emphasis on the concept of each of these types of measurements and various tools used by professionals to obtain these values. Two of the lessons discuss the concept of scaling and instruments used in scaling for prototypes and design. These lessons have the students make scale models of chairs and discuss the use of certain materials over others in construction of a design or prototype. A third lesson discusses mass, weight, volume, and density and the different tools used to measure these values. One of the scaling lessons was given some major changes while the other two lessons were given minor changes. After finishing the formatting of all other units, we decided this one needed an additional lesson to draw in engineering concepts. It was decided that a lesson on density would be created which was named *Mass/Volume=Density.* The lesson also has the students use the techniques of finding volume by water displacement, which is a WPS benchmark and a valuable fundamental to understand.

*Unit G: Forces*

The benchmarks for this unit included the skill of inquiry along with Technology/Engineering. The lessons in this unit include *Design a Catapult, Let it fly, let it fly, let it fly*, and *Balloon Racers*. These involve the construction of prototypes and small simple machines like catapults and how to use concepts of forces in projects to make decisions on design. In *Let it fly, let it fly, let it fly* the students examine the forces on wings and planes and construct paper airplanes and balloons with wings to participate in races. Emphasis during design will be on how forces keep objects lifted. *Design a Catapult* has the students construct a catapult and participate in a contest for the longest distance of a marshmallow shot from their machine. Two of the lessons were in good shape with some minor changes and reformatting. For the *Design a Catapult* lesson, a detailed set of worksheets was created to follow the engineering design process in detail, which included assigning tasks and getting better at how to decide on designs from brainstorming.

# 6. Analysis of Findings

Throughout the 2005-2006 PIEE Project, the findings made by the group are what have shaped and formed the final product. In September 2005 the group set off to perform a task that the undergraduate group had minimal prior knowledge of and no experience doing. This task was to create and implement a fully functional engineering curriculum in the Worcester Public Schools grades 4-6.

Throughout the academic year the interactions of PIEE with students and faculty became a large influence on the decisions made about the means to solve the task. Test runs of the lessons performed by the teachers with students led to major changes made to the original condition of the PIEE project. These alterations were not only made to the lessons themselves, but also to the deliverables such as the bins used to store the materials used in the activities. Observations in the classrooms were used as a tool to create a product that can be easily maintained in the future years.

Prior knowledge and experience of both the faculty and students on the topic of engineering was greatly over estimated. This led to many changes in the format and content of the lessons. The ways in which the students reacted to the lessons being taught in the classroom had a direct effect on the decision making process. The students helped mold the style of the lessons. If the students seemed confused or unsure about the material being taught, the content of the lesson was clarified on the topics which confused the students. Along with student's reactions the teacher's reactions to the lesson plans and supplemental material were also taken into consideration. They helped to form the structure of the lesson plans. If the teacher had difficulty performing a lesson, changes and additions were made appropriately to assist the teachers.

## 6.1 Student and Teacher Learning

The most important finding that was directly related to the success of the project was the ability of the students to learn the material contained in the lesson plans and for the teachers to become more familiar with engineering concepts. It was found that it was easier to teach new concepts involving engineering to the students compared to the teachers although some instructors took learning engineering in stride.

The students show genuine excitement when PIEE members came into the classroom to help the teachers perform a new lesson. Many of the students would approach PIEE members to share that they had been talking to family members about the new lessons in class and some found out they had engineers in their families. The students also showed interest in engineering by telling about their dreams and aspirations to become engineers when they grew up. Some students even told team members that they wanted to come to WPI to become and engineer because it sounded like “so much fun”. It was also observed that by the second half of the implementation process, students were becoming more familiar with how to approach problems and were working better in groups.

It was found that the teachers gained a better understanding of the fields of engineering and the exciting innovations that are produced by professionals in the career. At times it was difficult to get the instructors to incorporate all of the concepts but working closely with each teacher proved to be very beneficial. The overall success for the teachers was that within a few months of working with them one-on-one, all the teachers had embraced engineering. They showed greater interest in learning more about the lesson plan topics proposed.

## 6.2 Learning from the Students

For almost all the students the only history they had with engineering concepts was what they had learned from the past two years of the PIEE Project. The lessons were focused to accommodate them by starting out with lessons that teach what engineers do and the differences between the fields of engineering. Many of the students knew what engineers were, but had difficulty understanding what tasks they actually performed. To remedy this, problem solving activities that the students would be able to relate to were included in the lessons. It was found that there was a direct correlation between activities performed in the lessons which the students were familiar with and how well they understood the engineering concepts. Lessons executed in the classroom that students had no prior knowledge of did not have as great an impact on the students as a lessons that coincided with the material taught in the classroom that year. In order to eliminate such confusion for the students; additions were made to lessons to base them off of the current WPS benchmarks and MA Frameworks in the areas of science, technology, and skills of inquiry. This way the PIEE group created lessons that did not stray from the other academic materials students were currently studying. Classrooms were able to learn a science topic and at the same time have an engineering lesson as a supplement to that information.

Hands-on activities were favored by the students. Lessons that contained a construction or drawing activity appeared to have a more lasting impact than those lessons with question and answer worksheets. Many activities were added to the lessons to make learning engineering more involved and exciting for the students. It made a big difference in student cooperation and absorption of the material if the students were excited when they heard that they will be doing a lesson in engineering. These activities tried to incorporate real life situations like saving a village at the base of a volcano, as mentioned earlier. This helped to show the students that what they were learning in the classroom could be used later in life.

Many of these activities also included ways to make the lesson a competition between the students. Competition was found to be a great way to motivate the students to participate in the lesson. At the teacher's discretion, prizes could be awarded to the students to promote their participation. All of these additions to the curriculum came as a direct result of the reactions of the students towards the different types of lessons.

In order to show the students the procedure that an engineer performs in every day, more focus was put on the engineering design process. This principle was worked into as many lessons as possible; each step of the process was to be completed by the students. Worksheets which had the students perform each step reinforced the actions by an engineer when taking on a project.

## 6.3 Learning from the Teachers

The teachers also had a great influence on the structure of the lessons. Previous knowledge understood on the topics of engineering combined with their reactions to the content of the lessons helped to develop the final lessons. Teachers provided direct feedback on the lessons presented to them by PIEE. Each teacher had his or her own style of teaching, which supplied a wide variety of feedback.

The educators PIEE members interacted with during this project all came from different areas and had different academic backgrounds and knowledge of the various topics being incorporated into the lessons. Some had a stronger expertise in the sciences, while some had a stronger background in liberal arts. To compensate for this situation, background information was added to many of the lessons. This section includes all the information necessary for the teachers to gain a familiarity with the topic being taught. In a few instances, websites were added here for the instructors to pursue a greater knowledge of the topic. Even if the teacher had never been exposed to the information being taught, they had resources to use to help them teach the lesson as clearly and smoothly as possible.

The teachers' past experience in teaching also helped form the final format of the lessons. With years of prior experience in teaching, they are the primary source for how a lesson should be set up. They helped to make changes by filling out evaluation sheets, as seen in *Appendix 2*: Evaluation Sheet, supplied to them with and direct talks while visiting the classrooms. This information helped the PIEE undergraduates make changes to lessons' procedures where things were not clear for them, at places where they felt needed to be addressed more in depth, and where things did not run as expected in the classroom. For example, in a lesson in the Unit C: *Cells and Heredity*, one lesson called for the students to created encrypted sentences using DNA sets of proteins, e.g. GGAC – A, ACTG – B, and so on. This lesson was used to introduce the students with the structure of proteins in a DNA strand and make them more familiar with cell biology. However, during the lesson some of the students were trying to encrypt messages that were up to 30 letters. This led to extremely lengthy code that took the students a long time to encrypt and decrypt, which caused their enthusiasm about the lesson to drop. The teacher performing the lesson gave us feedback to possibly restrict the length of the messages that the student created. With that addition to the procedure of the lesson, the next time the lesson was performed, the lesson ran smoothly with no troubles.

The original intention for use of kits in the project was to have small bins that would hold the materials needed for the activities in the lessons. Each bin was intended to include the material for one activity. Throughout the year, with the addition of so many activities to the lessons due to the feedback from the students and teachers, it was found that one kit per activity would lead to a vast amount of bins to distribute to each schools. This would end up taking up much needed storage space and using an excessive amount of money for purchasing the numerous bins. It was decided one or two large bins that would hold all the materials needed for all activities would be made. Each grade at each school would receive their own bin. Along with the materials for the activities, the bins contain a list of all the materials within, which states the amount of the material, cost, and location of where to purchase the material when it runs out. This provides a way for the kits to be sustained in future years. With the cost of the supplies written out, teachers could easily show the school board the cost of the supplies for refunds and which would make the process of refilling the bins run smoother for the teacher.

Using both the student and teacher criticisms and feedback, the final lessons were created to include all the information and structure necessary to make an effective curriculum. With these lessons complete and in the correct format, the teachers and students should not have difficulty incorporating any additional lesson plans into their current curriculum or making additional changes if they deem it is necessary to the curriculums' success. The main focus for these final products is for them to continue being used in the curriculum taught in the Worcester Public Schools, even after the PIEE project has ceased. The teacher's feedback was most useful while finalizing lessons to allow this to happen. They are the people who will be working to continue and preserve these products in future years. If they are comfortable with the materials at hand, they will not be as hesitant to make proper changes when needed to the curriculum. The overall success of the curriculum and supplemental material provides the students and instructors with enjoyable and educational experience in the classroom.

# 7. Conclusions

The PIEE, grades 4-6 project had multiple successes and faced some challenges. The project successfully created a curriculum with engineering concepts, in a neat and organized manner. It was verified that the lessons within the curriculum could be used by teachers without an engineering background. Student's enthusiasms implementing the engineering design process increased. Educators gained a better understanding of the difference between engineers and scientists. Large engineering bins full of the materials needed to complete the activities in the lessons have been created. However, a difficulty of the project was communicating ideas and concepts with the teachers and increasing their comfort level with teaching engineering.

Once lessons became finalized, the undergraduate students of the PIEE project, along with their respective fellows attended the implementation of the lessons in the classroom. The undergraduates and the fellows provided assistance to the teachers while the lesson was executed. When a teacher misunderstood one of the steps in the lesson procedure or an engineering concept, one of the PIEE team members would clarify what was to be done. A general qualitative assessment of how well the teacher understood the material was made during these observations. The PIEE teams also walked around the room during the lesson to make sure the students were on target with the task at hand. It was noted whether the students were having trouble with the way the assignment was presented and if any changes in the procedure would improve how well the students understood what was expected of them. Having PIEE team members present while the

**Figure 10: Catapult designed in lesson 6.G.1 by Elm Park 6th grade**

lessons were being used provided direct proof that the curriculum would be able to be used in the future without them present.

The quantitative proof that the lessons were satisfying the goals of the project came from the worksheets for the students in the lessons and the evaluation forms filled out by the teachers. For each lessons, there are attachments of worksheets that the students use to follow the lesson and record what they are doing. By looking at the worksheets, the PIEE team was able to see whether or not the students were able to follow the materials and how well they understood the point of it. For example, in lesson 6.G.1, Catapults, there are worksheets provided that outline the engineering design process and provide space for the students to write something about what they did during each step. There are specific tasks on the sheets where their brainstorming of designs should be drawn. During the implementation of the lesson, some of the students only communicated one idea, but the on the worksheet it says to sketch and label a minimum of three ideas for the brainstorming. This implied that the students were not grasping the concept of brainstorming well, so the lesson was adjusted to stress the importance of brainstorming and reviewed its purpose. The assignments filled out by the students provided a representation of how well they understood the engineering concepts being presented in the lesson.

The lesson evaluations were not as successful as expected by the PIEE team. A general template with questions pertaining to lessons was developed and given to the instructors to be filled out after each lesson was implemented in the classroom. Unfortunately many of teachers were very busy and could not complete the evaluations in time to be effective, did not give good criticism or details on the sheets, or the teacher never received a copy of the evaluation sheets. The absence of evaluation sheets was most problematic for the lessons that were implemented in the classroom this year that the PIEE team was not present for. This can be blamed on scheduling conflicts due to the time crunches in the elementary schools and courses at WPI. Even though most of the teachers had copies of the evaluations sheets, they were not always reminded to fill them out when the PIEE members were not there during an implementation. Although many were eventually filled out, the comments showed a reflection of the lesson much after it was actually implemented (up to a month). These comments still gave us insight into how well the lesson worked in the classroom, but many times did not include details and suggestions for fixing the lessons. This was not necessarily a bad thing, many of the lessons didn’t need to be changed, but healthy criticism is always more helpful then no criticism.

An overall enthusiasm of the students during the lessons being implemented was accomplished. Some students enjoyed the group work associated with the lessons, while others were excited to be able to exercise their level of creativity. Most of the students enjoyed the design lessons because it became a competition among the groups to create the best design. Motivation by group leaders was also present during the lessons. Many times, one person in a group would be more interested in the task, and delegate others to complete certain measures to reach the goal of the assignment. Students seemed to appreciate how the engineering lessons incorporated math and science skills applied to something one would see in “real life” situations. Students began to make a stronger connection between things they use on a regular basis to the type of engineer involved in its design. The majority of the students had a good attitude during the lessons, even when there were issues with group dynamics, or specifically one student in the group not participating. As a culmination to the PIEE project a showcase was set up where the participating students could come and show off the work they had completed this year. The showcase was a major success due to the overwhelming number students and faculty of the WPS that came to display their creations. A feeling of pride and accomplishment was sensed in the students as they explained to the various faculty members and parents the creative work they put into these projects. The showcase really helped to show the community as well as the students how much work and effort was put into these lessons.

One of the primary challenges the PIEE team faced with the project was working with the teachers. Some of the teachers expressed a degree of excitement for the project, and others hesitated to agree to participate. Those who were reluctant to teach the lessons felt that they did not have the expertise to be teaching such concepts and that the lessons would be taking away from the time the students needed to spend on their other subjects to prepare for MCAS testing. It was explained that they did not have to be proficient in engineering in order to teach it, and that the lessons created were very well rounded and could be applied to the science and math skills practiced in the classroom. Some of the teachers continued to struggle with the objectives of the PIEE project, and others took it in stride and eventually became more comfortable teaching the lessons. The teachers that had trouble absorbing the purpose of the project would try to have the PIEE team members who came in during lesson implementation actually teach the lesson. They did not understand that the intent of the project was to develop lessons that anyone would be capable of picking up and teaching to a classroom. The teachers that eagerly partook in the lessons are an element of success in the PIEE project. The PIEE team hopes that these individuals will share their interest in the lessons with others so the curriculum begins to be used by more teachers.

The deliverables of the PIEE project were completed successfully. The binders for the teachers were created with uniformity and good organization. All of the lessons were included with markers separating them so they could be found easily from the table of contents. Over head projections of certain handouts and of attachments meant to be shared with the classroom were also printed and included in the binders. One set of binders was given to each of the schools, Elm Park Community and Midland Street. Each page of the binders is in sheet protectors to ensure that the binders will be long lasting. Before the binders were created, the lessons had to be evaluated and edited one last time, and the files were renamed so there was consistency in the format. By doing this, it made it easier for the PIEE integration team to take all of the lessons and keep them organized for compiling the entire PIEE project with all grades. The PIEE integration team has a goal to take the lessons from the 4-6 teams and put them with the lessons from grades K-3 to form one database. This database would be organized by lessons topic and grade so a search could be performed. The ultimate hope is to create a web page for the PIEE project where this database could be accessed.

The engineering bins were the supplemental deliverable to the lessons. The original goal of the project was to create one bin per lesson with all of the materials needed to complete it. Due to the fact that this would take up too much space and would be difficult to organize, the idea of having one large engineering bin for each grade was proposed and accepted. The engineering bins that have been created include all of the materials for all of the lessons in the curriculum for each grade. Many of the materials are needed in multiple lessons, and only a small portion, which is another reason this bin is more convenient. For example, in one lesson it may call for each student to have 2 toothpicks, but a larger pack of toothpicks is less expensive, and there are other lessons that also call for the use of them. Having the bin allows students to step outside the realm of the lesson if they desire to find alternative materials to be used in a lesson that specifies certain materials.

The PIEE project for the 4-6 teams has been a successful mission for the academic year of 2005-06. The challenges faced were overcome as described above, and the initial goals set by the team were made within the time expected. The deliverables were also presented to the schools in time. Most importantly, the team successfully increased student's interest in engineering, and the accomplishments made can be added to in the future to expand the engineering education of Worcester Public Schools grades 4-6.

# 8. Recommendations

To implement an engineering curriculum across the entire Worcester Public School system was beyond the scope of the PIEE project. During the process of creating the curriculum and implementing the lessons in pilot classrooms, the challenges faced and evaluations made led to a better understanding of how the project could be instituted in subsequent classrooms.

The overall success of the PIEE project for the 4th, 5th, and 6th grade in both, Elm Park Community and Midland Street Elementary Schools, relied heavily on the teachers and staff of both schools. The completion of the PIEE project laid a strong foundation for engineering education in WPS. Due to the changing nature of science and engineering, the continuation of the project, its maintenance, and its further construction must be executed by the parties involved with the project at the schools. To contend with this issue, the PIEE team has formed recommendations to help successfully continue the realm of the project, based on experience associated with elementary engineering education.

The first aspect of the curriculum that poses an issue in the up-coming years is how to be sure supplies for engineering bins will be replenished. Upon the completion of the project, there will be no monetary assistance from WPI or the NSF to maintain the project. The bins that have been left behind provide the necessary materials to perform each lesson in the curriculum. This problem was foreseen so the PIEE 4-6 team developed the solution to provide materials that are re-useable and inventory sheets. These sheets provide information to make the purchasing of perishable and non re-useable materials as easy as possible for the instructors. The engineering bins have also been organized as best as possible to facilitate them being re-supplied and used by the instructors. Ultimately, the responsibility to maintain and re-supply these bins as they are used by the students to perform the tasks in each lesson lies in the hands of the instructors.

The team suggests that the instructors should use the inventory sheets that accompany each bin as an ongoing check list of the materials within. When the materials become low, it should be marked down on the sheet. At the end of each year this check list should be consulted. Summers could be spent stocking up on the materials needed. The inventory sheets provide estimates of what each material will cost and where to find it. All instructors using the lessons are encouraged to collaborate and share the efforts necessary to keep a constant amount of the needed materials.

An active role should also be taken by the instructors to evaluate the materials in the kit. As they perform the lessons they should think of ways to improve the materials that they may need. Some materials may be substituted for generic products or students could be asked to talk to their parents to bring materials they may have around home to class to cut costs.

The continued success of this project also relies on the parties at the participating schools to play an active role in updating the lesson plans. Due to the ever-changing nature of science, technology, and engineering the information contained in the curriculum will need to be updated. The instructors can tailor the lessons to their own teaching style for easier implementation in the existing curriculum. One off the most crucial aspects of the continuation of this project is ensuring the education and training of the teachers.

Many of the issues of implementing engineering into elementary education stemmed from the lack of awareness of engineering. The students had not been introduced to the concepts of engineering problem solving and many of the teachers were also unfamiliar with these concepts. To assist teacher's comfort level with the material, the team tried to include background information on the engineering concepts and detailed descriptions where necessary. To teach engineering concepts adequately, the educators need to be able to understand the concepts they are teaching.

The most important recommendation the team can make is to promote teachers keeping themselves familiar with the engineering concepts they are teaching and to keep their classrooms up to date with the current field of engineering and technology. This would require the instructors to play an active role in learning new emerging technologies and new techniques on teaching engineering. There are supplemental resources available on the web and magazines that can aid in the development of the instructor's ability to teach engineering and technology.

To make it easier for instructors to improve their skills in teaching engineering education and their knowledge of the field of engineering, these resources could be provided on a brief reference sheet which would explain the overall concept of engineering, engineers, and technology. Whether it is in the form of magazines, news letters, journals, or books, instructors should be provided sources they can turn to if questions arise. This way they would be able to explain concepts in more detail, and simply spark student's interest by giving updated examples on how engineering is changing the world or helping people live better, safer, happier lives.

A helpful tool for instructors would be to become computer literate. Not all teachers are aware of the advantages of the internet, and need to be trained to use other programs available. There are multiple other projects in America dealing with similar issues that this project faced. Many have websites directed to educators that offer information on engineering and how to become more comfortable teaching basic concepts. Basic computer skills could help instructors come up with new lessons and activities that make it easier for students to learn the knowledge necessary to be proficient in engineering and technology. To further the success of this project, instructors could create a large list of resources or one could be provided to them so they can use it to better themselves and their students.

Small resources were worked into the lesson plans but are only an example of the vast amount of information available to instructors who want to take in active role in their students understanding of engineering. Instructors should be provided a wide variety resources and a means to acquire these resources so that they can consult them when they want to update themselves or their teaching techniques. This would certainly contribute to student's success in understanding and appreciating engineering and technology.

Another recommendation that ties in closely to the instructor's active role in engineering education is general awareness in engineering, science, and technology. Engineering is stereotyped as a profession for only those who excel in the areas of math and science during elementary and high school. This is not completely true, not everyone who does well in school has the ability to become an engineer or pursue a career in the field engineering, and some students who struggle with details of school are candidates for becoming and engineer. Everyone has the opportunity to see if engineering is right for them. There is also a lack of understanding of what an engineer does, how important they are to modern society, and that a problem with the lack of engineering education even exists.

This group recommends that to positively influence the introduction of an engineering curriculum there should also be an increase in the awareness of engineering in the general public including, teachers, students, parents, and anyone else who will listen. Teachers are the glue that holds the whole puzzle of introducing engineering education together. It is the responsibility of the teachers to not only learn to teach engineering concepts and understand technology, but to also promote a positive future in engineering for everyone that is independent of race, age, sex, or ability. The stereotypes that only white males can aspire to have a profession in engineering have been outlived, and are an unwanted infection in modern society.

Awareness needs to be raised, and teachers are the first responders to this problem. During the implementation of the project, students expressed that they desired to become engineers and go to college. Before the PIEE project, this may not have been even a suggestion for them. Teachers need to play an active role in emphasizing equality in engineering and the importance of an engineer in the world, as well as teaching basic concepts.

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## Appendix 1: Evaluation Sheet

**Lesson #:**

**Lesson Name:**

**Teacher:**

**School:**

**<u>Evaluation of Lesson Plans</u>**

1. Did the lesson hit the goals of the benchmark effectively?

2. Was the lesson plan easy to follow?

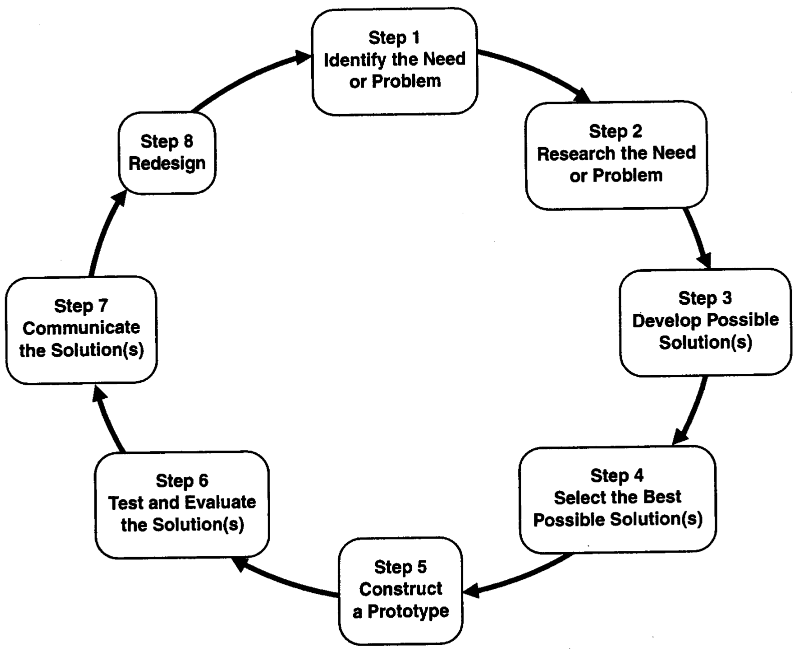
3. Was there a classroom activity that included the whole class? If so, did the entire class participate?

4. Was the lesson plan clear to the students?

5. Did the students show interest for the material in the lesson?

6. Was there a kit provided for the lesson? Did it provide its intended purpose for the class?

# Appendix 2: Steps of the Engineering Design Process [20]




1. Identify the need or problem
2. Research the need or problem
   - Examine current state of the issue and current solutions
   - Explore other options via the internet, library, interviews, etc.
3. Develop possible solution(s)
   - Brainstorm possible solutions
   - Draw on mathematics and science
   - Articulate the possible solutions in two and three dimensions
   - Refine the possible solutions
4. Select the best possible solution(s)
   - Determine which solution(s) best meet(s) the original requirements
5. Construct a prototype
   - Model the selected solution(s) in two and three dimensions
6. Test and evaluate the solution(s)
   - Does it work?
   - Does it meet the original design constraints?
7. Communicate the solution(s)
   - Make an engineering presentation that includes a discussion of how the solution(s) best meet(s) the needs of the initial problem, opportunity, or need
   - Discuss societal impact and tradeoffs of the solution(s)
8. Redesign
   - Overhaul the solution(s) based on information gathered during the tests and presentation